Distributed Generation & Microgrids: Is There a Limit to Decentralization?’

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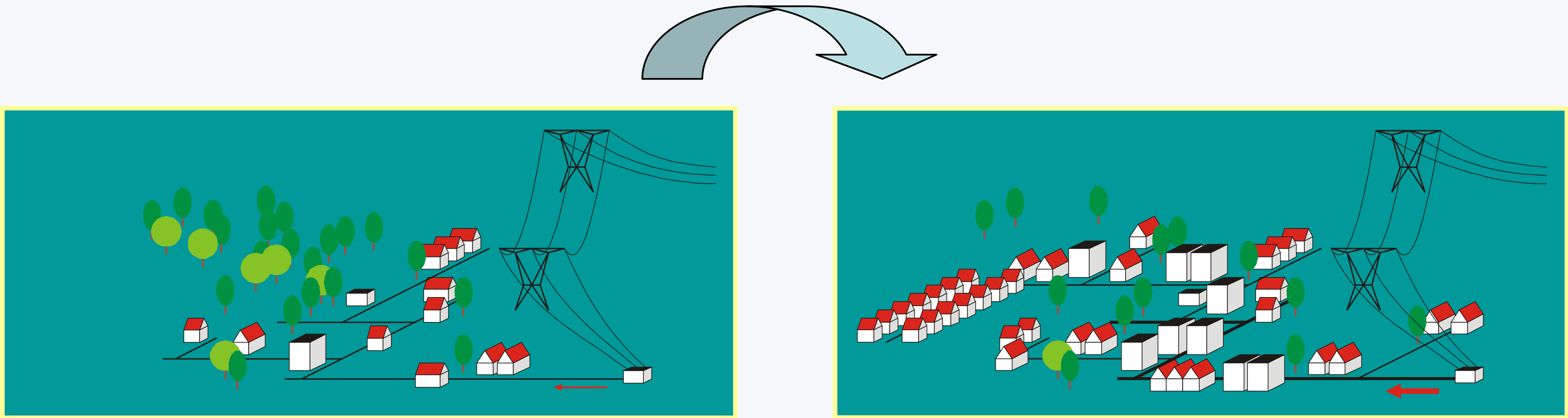
Traditional low voltage grid



- Limited number of loads
- Energy supplied top-down from central power station

- Increased loading
- Increased distortion: due to non-linear (power electronic) and sensitive loads power quality problems arise)

Evolution in electrical energy

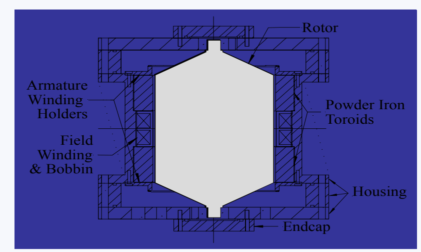
- 3 *technological drivers*
  - Power electronics (PE) becomes ubiquitous in loads, generators and grids
  - More power produced (and stored) near consumers: Distributed Energy Resources (DER)
  - Increased importance of Power Quality (PQ): more disturbances and more sensitive devices

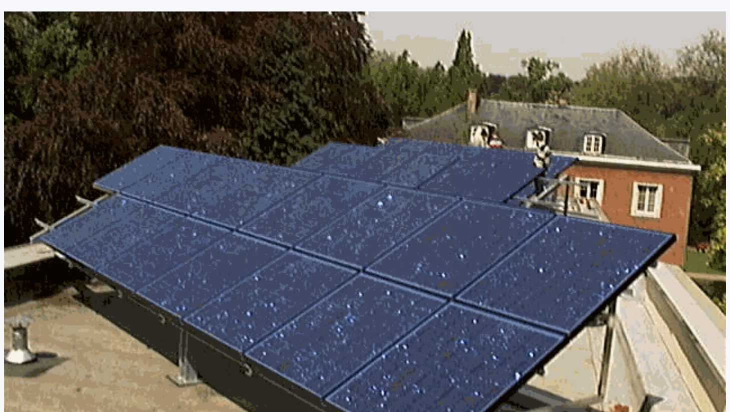
- 3 *socio-economic tendencies*
  - Liberalization of energy markets
  - More sustainable energy (renewable and ‘high-quality’)
  - Non-guaranteed security of supply

DER technologies

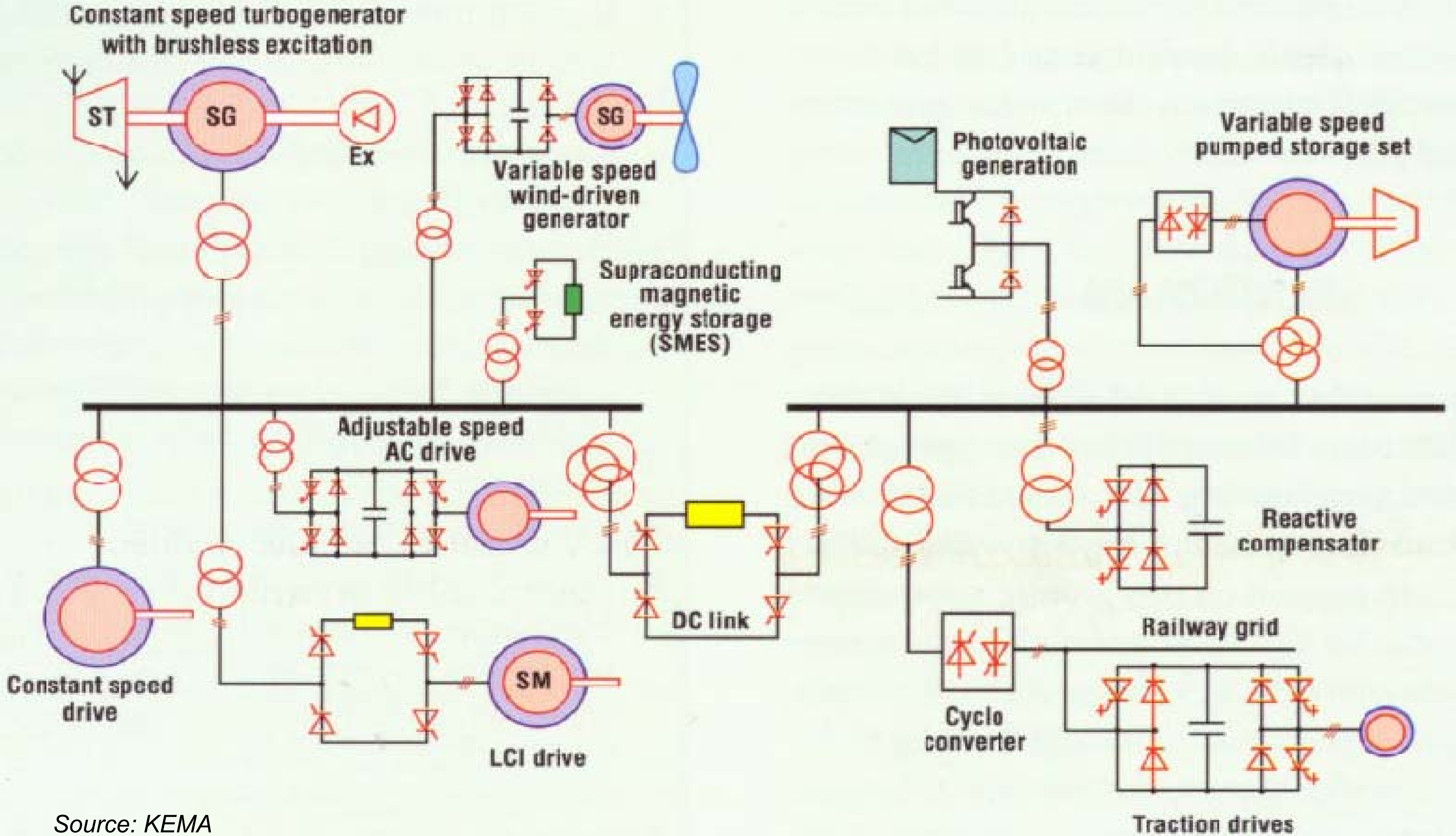
- Distributed Generation:
  - Reciprocating engines
  - Gas turbines
  - Micro-turbines
  - Fuel cells
  - Photovoltaic panels
  - Wind turbines
  - CHP configuration

- Energy Storage
  - Batteries
  - Flywheels
  - Supercapacitors
  - Rev. fuel cells
  - Superconducting coils





Power electronic dominated grids



Source: KEMA

Grid of tomorrow ?

- Local generation
- Local storage
- Controllable loads
- Power quality and reliability is a big issue

- System's future size?
  - Growth:
    - **Consumption rises annually 2-3%**
    - **Investments in production: very uncertain**
      - **What is accepted? What is possible in regulatory framework?**
  - Short-term: make balance by introducing DG?
  - Long-term: more storage and/or 'activate loads'?

Microgrid ?

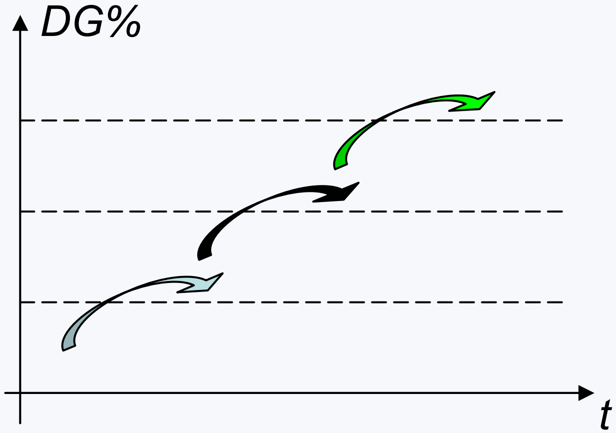
- Grids may even separate from central supply
  - No net power exchange: total autonomy
  - Important aspect, characterizing a *Microgrid*
    - **"Ancillary Services"** are all delivered **internally**
      - **Balancing the active and reactive power**
      - **Stabilizing the grid: frequency, voltage**
      - **Providing quality and reliability: unbalance, harmonics, …**
- Is a Microgrid new ?
  - It all started that way, before interconnection
  - In fact, no: the grid behind certain UPS systems are driven like a microgrid with one generator

How much local sources can a distribution grid accept ?

- Distribution grid was *never* built for local power injection, only top-down power delivery
- Electrical power balance, anytime, in any grid:

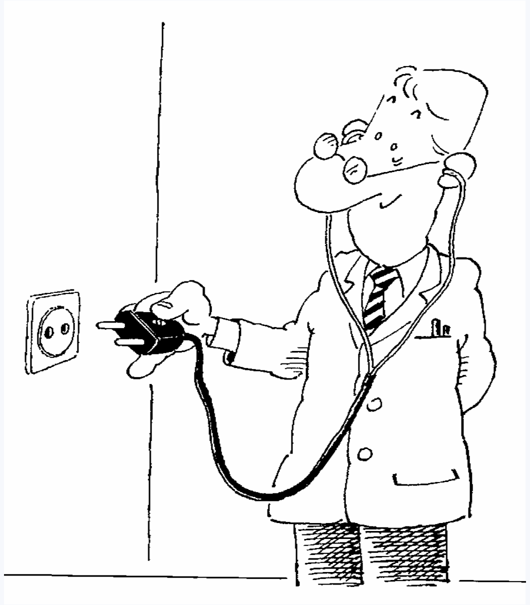
  Electricity produced - system losses = electricity consumed - storage

- Barriers to overcome:
  - Power quality & reliability
  - Control, or the lack of
  - Safety
  - Societal issues
  - Economic aspects



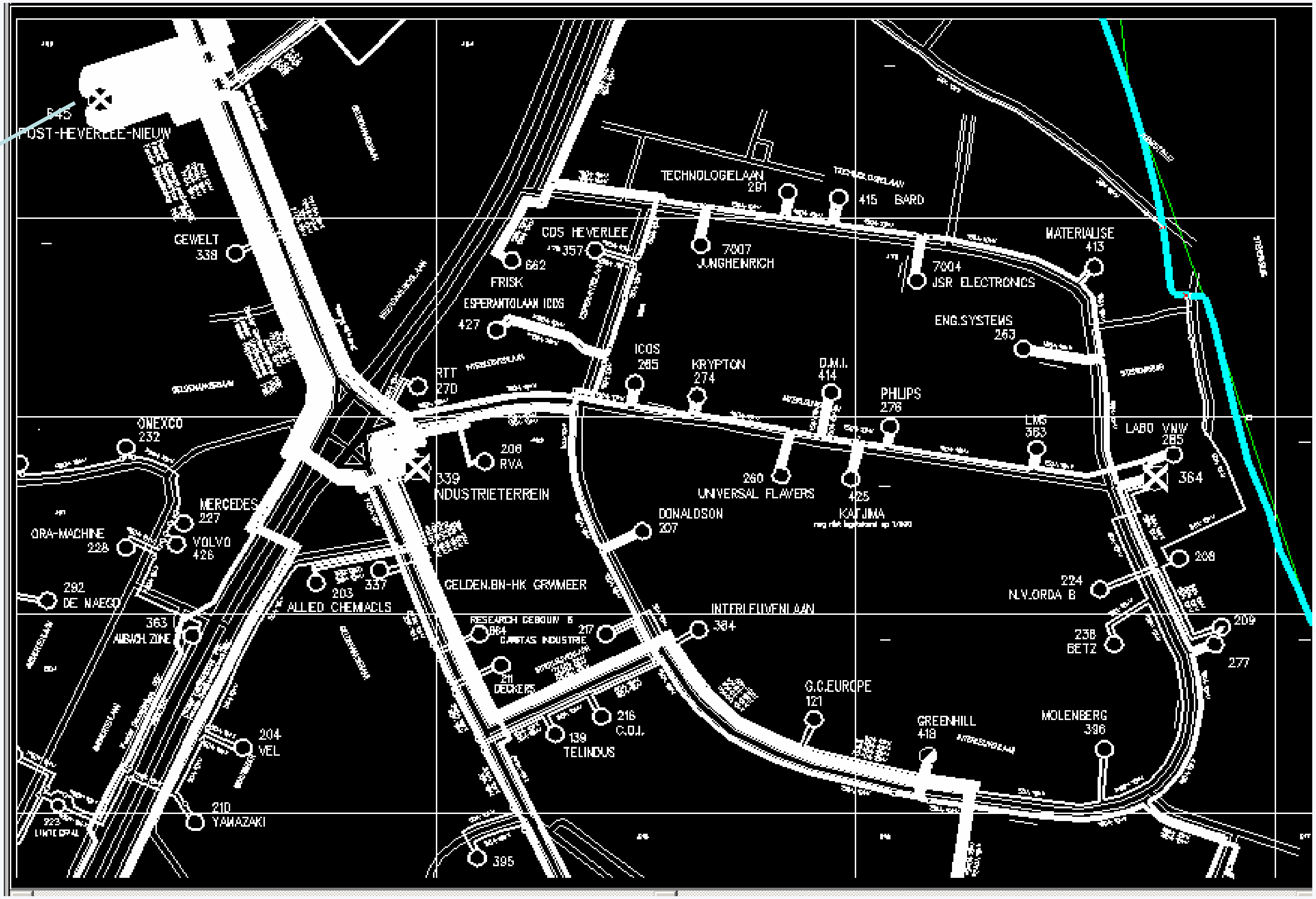
Power quality & reliability

- Problem:
  - Bidirectional power flows
  - Distorted voltage profile
  - Vanishing stabilizing inertia
  - More harmonic distortion
  - More unbalance
- Technological solution:
  - Power electronics may be configured to enhance PQ
  - DG units can be used as backup supply



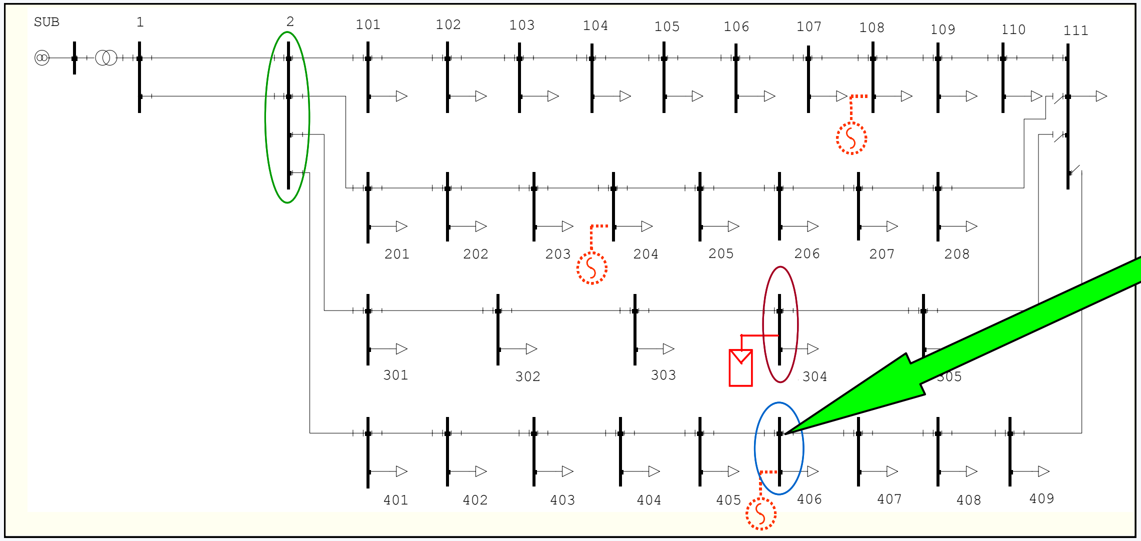
Example: MV cable grid

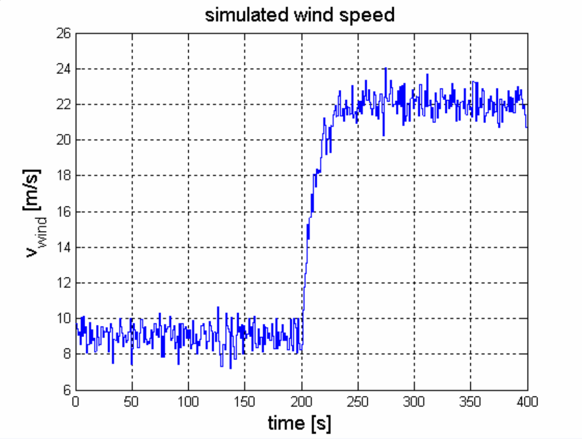
Substation connecting to HV-grid

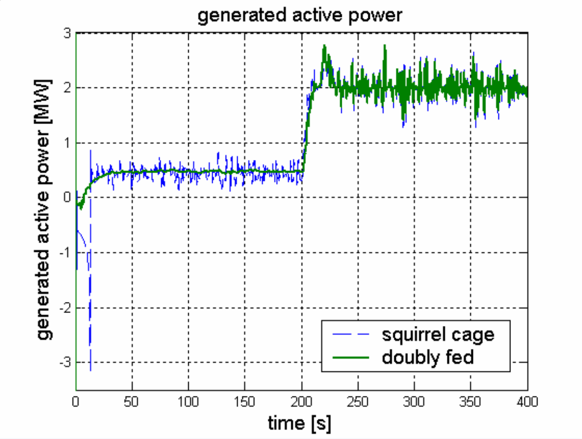


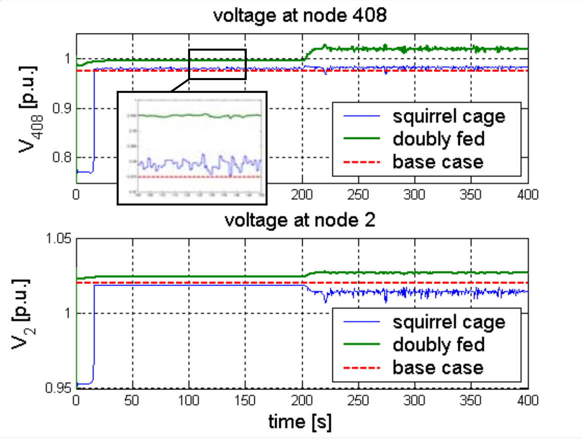
Location: *Leuven-Haasrode*, *Brabanthal + SME-zone*

Impact of wind turbine



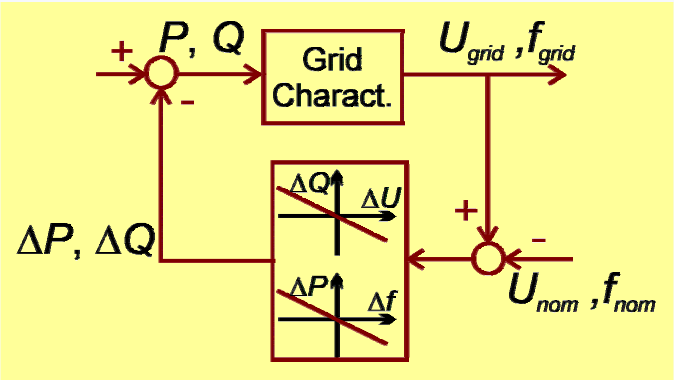






Control, or the lack of

- Problem:
  - Generators are *NOT* dispatched in principle
    - **Weather-driven (many renewables)**
    - **Heat-demand driven (CHP)**
    - **Stabilising and balancing in cable-dominated distribution grids is not as easy as in HV grids**



active power ⟺ frequency

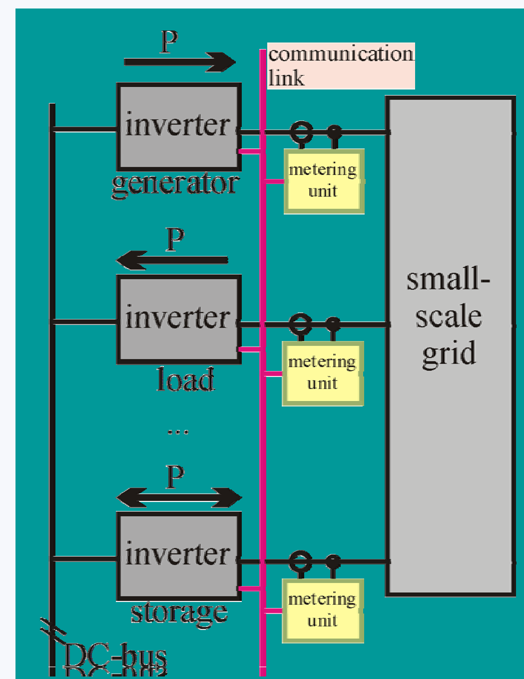
reactive power ⟺ voltage

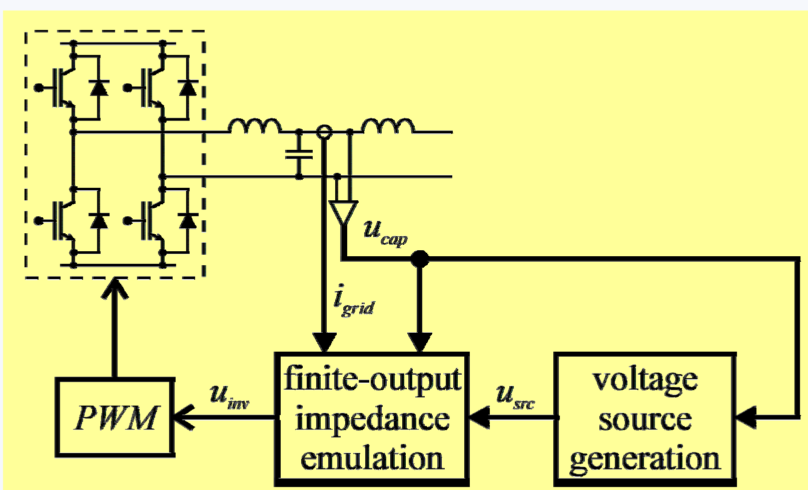
Networked system operations

- Solutions:
  - Higher level of control required to coordinate balancing, grid parameters ?
  - Advanced control technologies
- Future technologies, under investigation
  - Distributed stability control
    - **Contribution of power electronic front-ends (see example)**
  - Market-based control
    - **Scheduling local load and production, by setting up a micro-exchange (see example)**
  - Management of power quality
    - **Customize quality and reliability level**
  - Alternative networks
    - **E.g. stick to 50/60 Hz frequency ? Go DC (again) ?**
- Rely heavily on intensified communication: interdependency

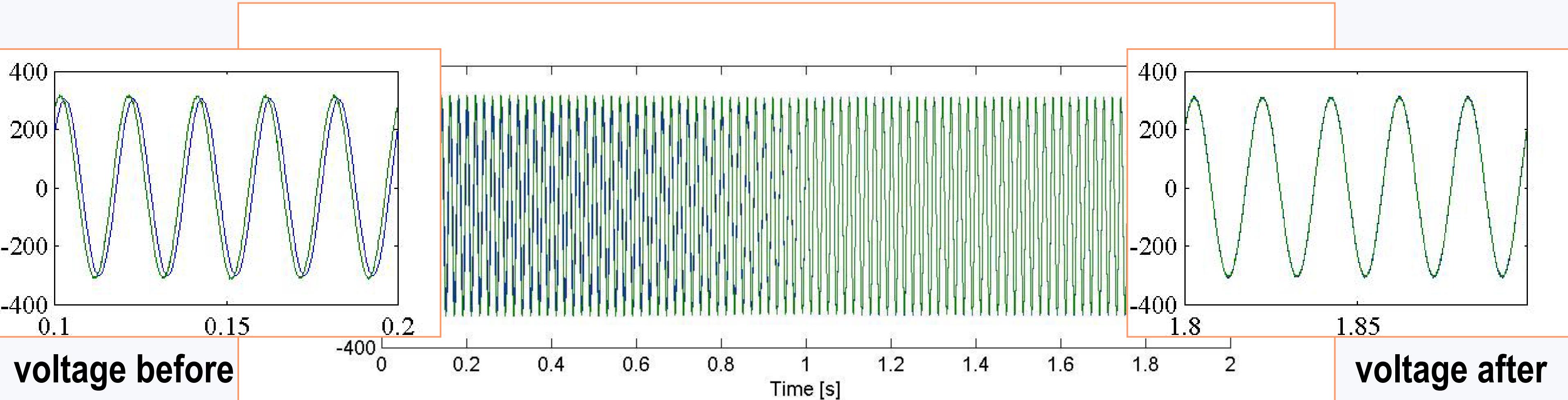
Example: fully decentralized control

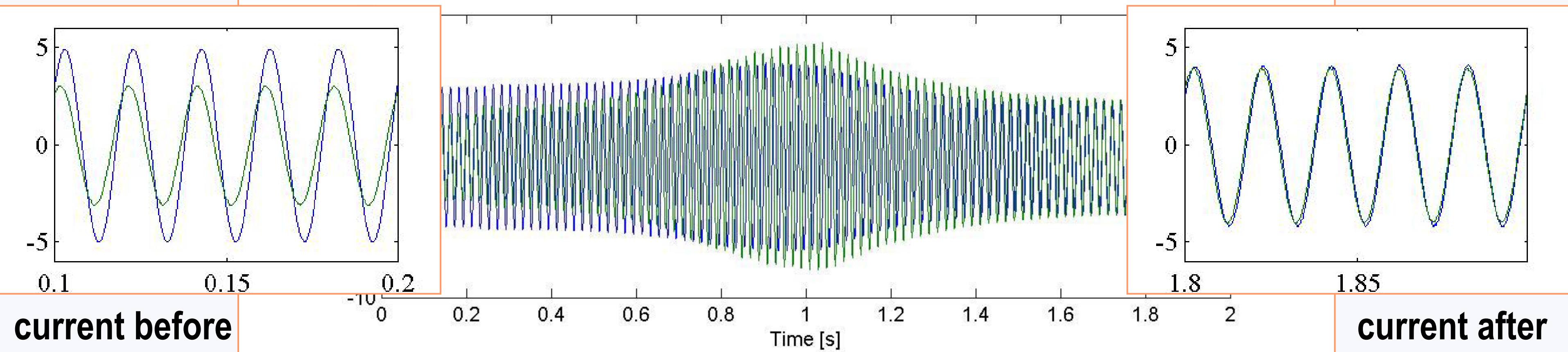
- Standard method: “droop control”
- KUL method: Virtual Impedance method
  - Emulate a voltage source with internal tunable impedance in the time domain
  - Ref.: K.De Brabandere et al. @ PESC’04
- Advantage: seamless transition from grid-connected to island and reconnect





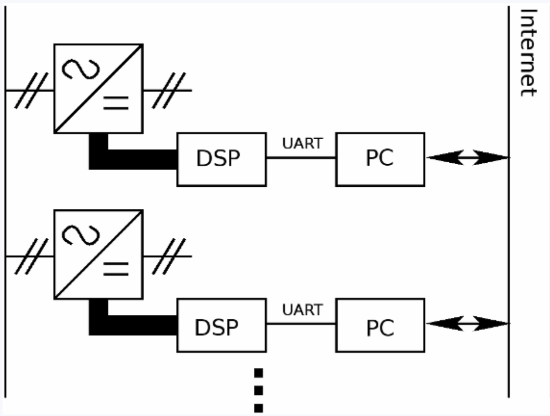
Experimental results: connection of two independent grids (islands)

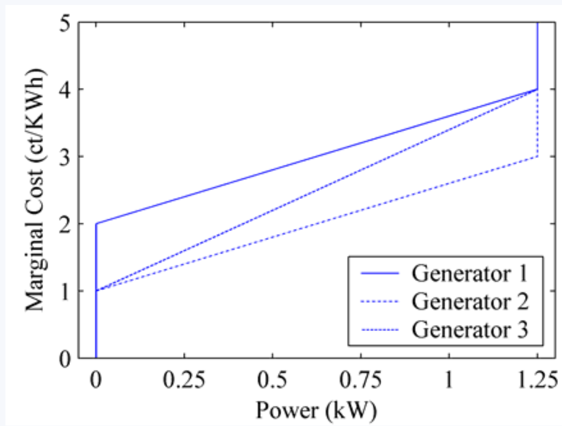


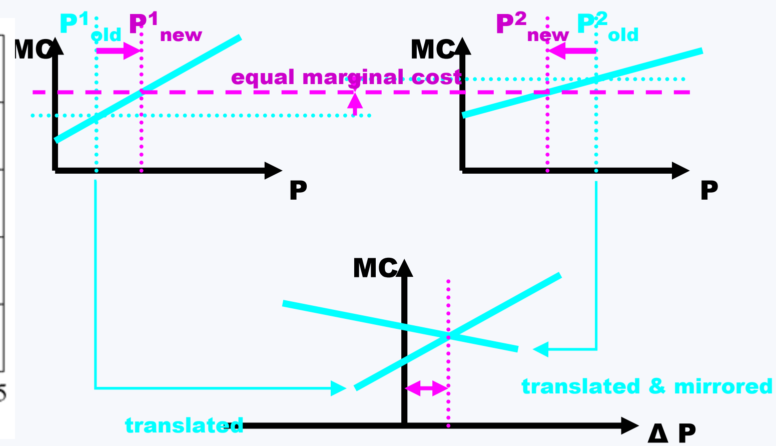


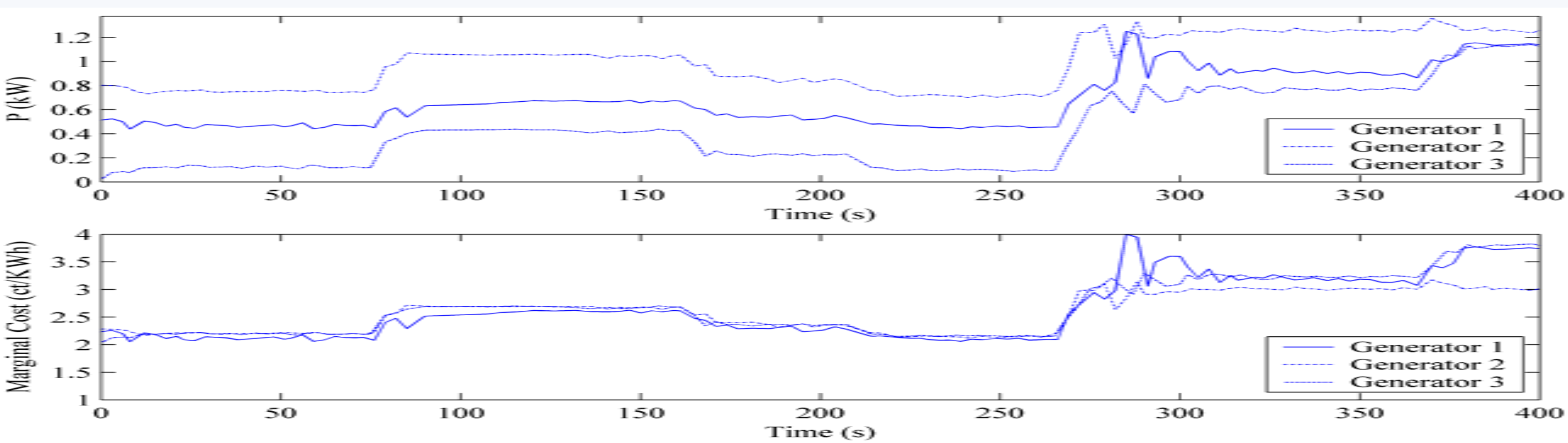
Example: tertiary control on local market

- DG units locally share loads dynamically based on marginal cost functions, cleared on market



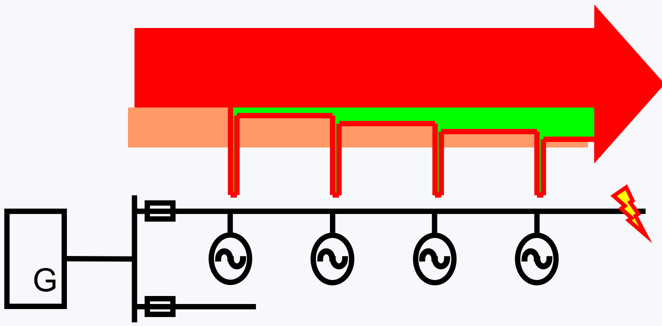


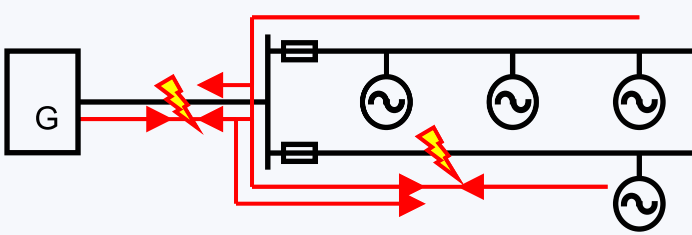




Safety

- Problem:
  - Power system is designed for top-down power flow
  - Local source contributes to the short-circuit current in case of fault
    - **Fault effects more severe**
    - **Difficult to isolate fault location**
  - Bidirectional flows
    - **'Selectivity' principle in danger: no backup 'higher in the grid' for failing protection device**
  - Conservative approach on unintentional islanding
- Solution:
  - New *active* protection system necessary





- Problems:
  - Environmental effects
    - **Global: more emissions due to non-optimal operation of traditional power plants**
    - **Local effects as power is produced on-the-spot, e.g. visual pollution**
  - Making power locally often requires transport infrastructure for (more) primary energy
    - **Problem is shifted from electrical distribution grid to, for instance, gas distribution grid!**

"DON QUIXOTE IS HIS NAME AND HE JUST CAN'T STAND THESE!"

- Solution:
  - Multi-energy vector approach
  - Open debate on security of supply

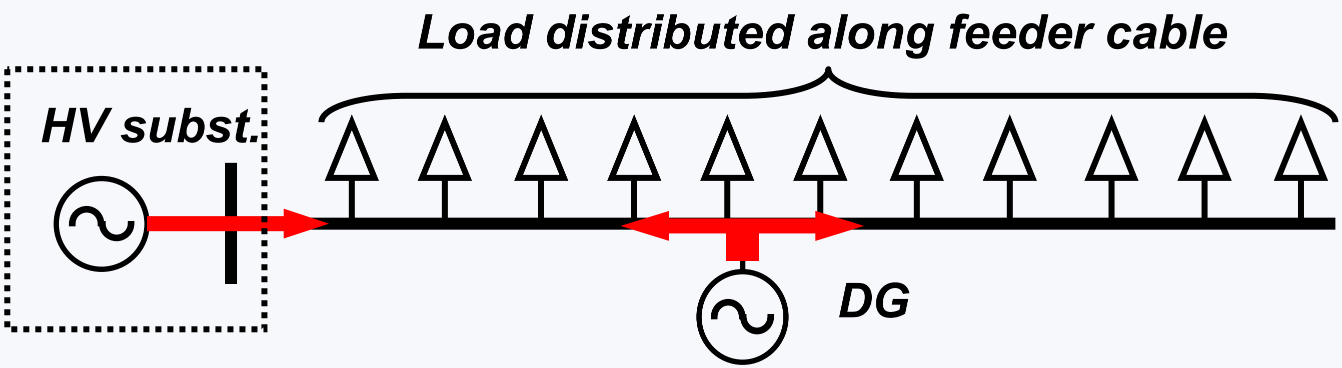
Economic issues

- Problems:
  - Pay-back uncertain in liberalized market
    - **‘Chaotic’ green and efficient power production**
    - **Reliability or PQ enhancement difficult to quantify**
  - System costs
    - **More complicated system operation**
    - **Local units offer ‘ancillary services’**
  - System losses generally increase
  - Who pays for technological adaptations in the grid ? Who will finance the backbone power system?
    - **Too much socialization causes public resistance**

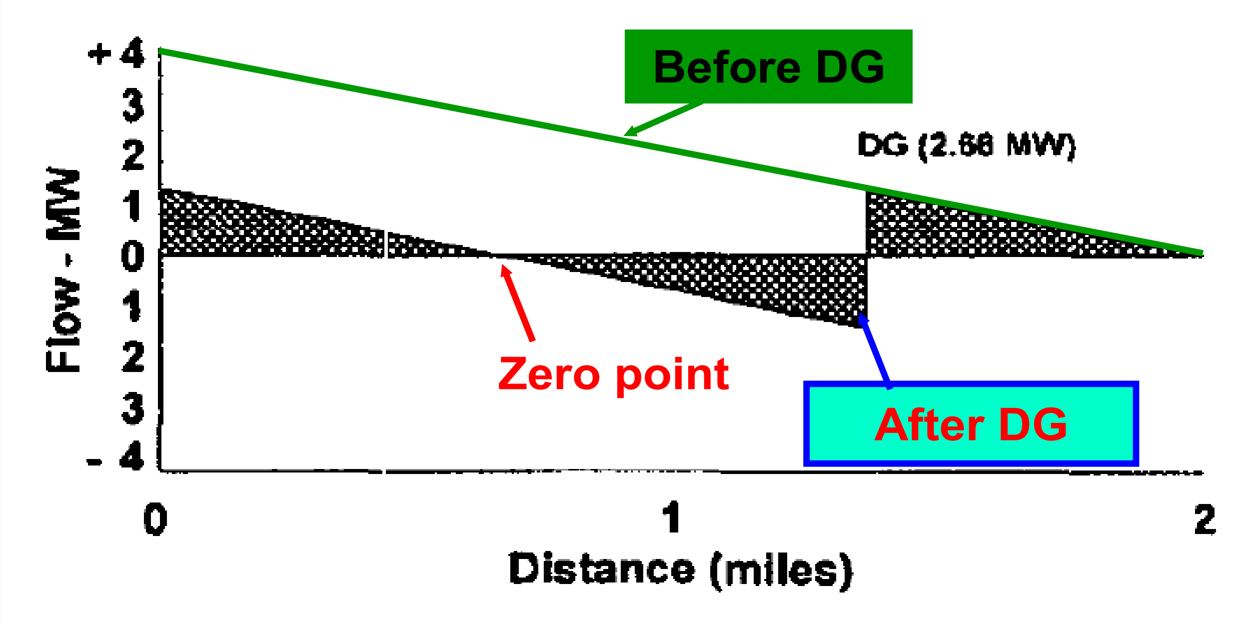
- Solution:
  - Interdisciplinary regulation, not only legal
  - Need some real ‘deregulation’

System losses example

- DG introduction does not mean lowered losses
- Optimum is 2/3 power at 2/3 distance
- Other injections generally cause higher system losses



Power flow along cable



Balancing question, again

- Fundamental electrical power balance,
  at all times is the boundary condition:

  Electricity produced - system losses
  = electricity consumed - storage

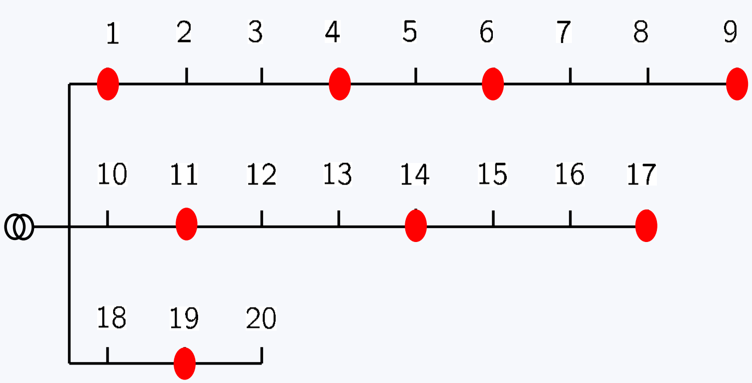
- All sorts of reserves will decrease in the future
- Role of storage? Storage also means cycle losses!
- Next step in enabling technologies
  - *Usable* storage
  - Activated intelligent loads (demand response technology), also playing on a market?
  - Boundary condition: minimize losses

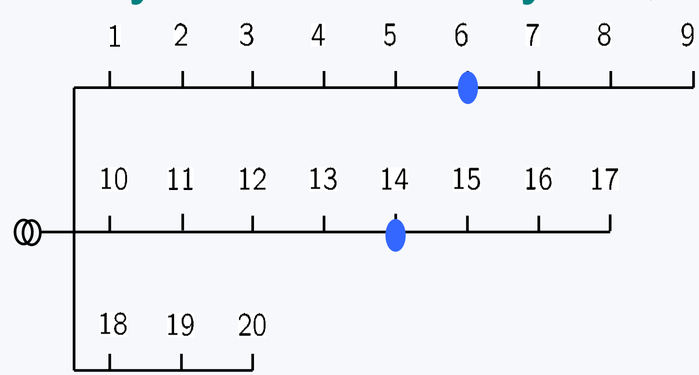
How far can we go?

- Large *optimization exercise*, considering the different technical barriers:
  - Optimal proliferation, taking into account local energetic opportunities, e.g. renewables options
  - Unit behavior towards grid: technology choice
  - control paradigm
  - Is the same level of reliability still desired ?
  - Level of introduction of new additional technologies (storage, activated loads)
- Optima are different, depending on stakeholder
  - E.g. grid operator vs. client

Optimization example

- Total problem yields a huge mixed discrete-continuous optimization problem
  - Optimization goals: voltage quality penalty, minimum losses, minimum costs
  - Complexity: sample grid yields 2^{40} siting options for simple domestic CHP and PV scenario → need advanced maths
  - Results are different hourly and vary with time of year,





e.g. during day: PV opportunities → in peak hours: CHP helpful

Conclusion

- Current grid:
  - Interconnection
  - Higher PQ level required
  - DER looking around the corner
- *History repeats: after 100 years the idea of locally supplied, independent grids is back*
  - *Microgrids, being responsible for own ancillary services*
- Maximum (optimal?) level of penetration of DER = difficult optimization exercise
- Special (technological) measures are necessary
  - E.g. in system control, mainly balancing
  - Role of loads?
- Not only technology push, but also customer pull

more information:

http://www.esat.kuleuven.be/electa

check *publications* sections, e.g.:

Pepermans G., Driesen J., Haeseldonckx D., Belmans R., D'haeseleer W.: "Distributed Generation: Definition, Benefits And Issues," Energy Policy, Elsevier, Vol.33, Issue 6, April 2005, pp. 787-798

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Thank you!

(now, let's discuss)